ELEVATOR SYSTEM DESIGN

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Abstract- *- Elevator is the device which is used to transfer people on different floors in a building, for doing so they use electric motors and worm gear box. A worm gear box consists of a worm gear & worm wheel. The input of the motor is given to the worm gear which in turn drives the worm wheel, to which pulley is attached. Worm gears are most suitable for transmitting power between two shafts that are perpendicular but not intersecting. They are mainly used for this application because of high-speed reduction ratio. In this paper we have focused on different systems such v belt system, brake system, counter weight system, rope drive, motor drive etc. which are nothing but the part of elevator system has been studied in detail.*

Key words*- Temperature, effectiveness, heat transfer.*

1. Introduction

The main requirement of the multi storage buildings are elevators for movement of goods and people. Elevators ease the work of human being and keep them in comfort zone. Elevator control system is needed to control all the functions of the elevator. It is the one which guides the elevator car, which actually carries the passengers between the different floors; it also controls the opening and closing of doors at different floor, and the safety switches are also controlled by the elevator control system.

Elevator system basically controlled with the help of motor. Motor is a device which converts the electrical energy to mechanical energy. This mechanical energy further used to lift the passenger car from the bottom. This motor drive basically connected to worm gear drive directly or through the belt drive. Most of the time belt drive is used for safety purpose. Further it is connected to the worm gear drive where speed reduction is taken place. The reason behind the use of worm gearbox is because it is having high speed reduction ratio. Along with this counter weight is one of the important parts of the elevator system. It is used to counterweight the system. As our main focus is on safety of the passenger, we generally use the shoe brake in the systems, mostly double shoe brakes are used. At the end of the worm wheel shaft sheave is mounted on which number of ropes are provided. These ropes are used to lift the elevator from the bottom. Along with this there some parts like shafts, key, bearings etc. are used in the system.

2. Problem Statement

The elevator is to be design for the overall capacity of 600 kg so as to transfer people on from bottom floor to 5th floor at the speed of 0.6 m/s. It takes the input power from the motor which is given to worm gear box so as to reduce the speed to the required level and torque.

3. Motor drive

Fig 1: 3 phase induction motor

In older days for traction purpose DC series motor was the best because of its very high starting torque. But there are several disadvantages of DC SERIES MOTOR

1. Poor speed regulation
2. Poor voltage regulation
3. Can't be started at no load conditions
4. Speed control can't be done smoothly without DC drives..

Due to this disadvantages DC series motor is obsolete now a days.

Now a days we use 3-phase induction motor with the aid of. Variable voltage variable frequency drive (VVVFD. These drives are used to control the speed of the induction motor very smoothly by controlling the fluxes it the motor.

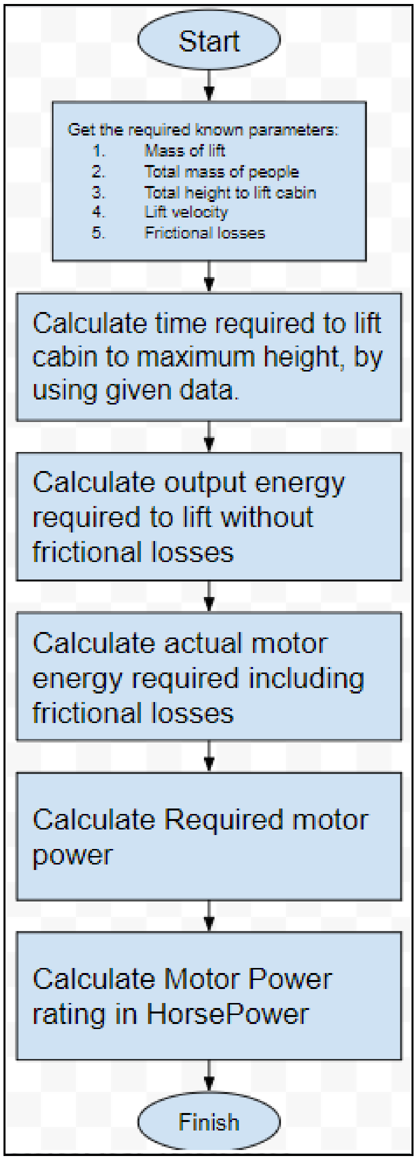
The voltage/frequency ratio is varied by this drive so that the flux per pole also varied in such a way that the speed is confidently controlled but one thing has to be remembered, the controlling of that ratio has to be done by avoiding flux saturation in the air gap.

The advantages of using be VVVFD are:

1. The speed control can be done easily by varying the airgap fluxes
2. No permanent magnets are used so there will be very less hysterisis losses
3. Electronic speed control of induction motor makes the motor very efficient and effective.
4. The braking operation can be done without any restriction.

Flow chart of motor design:

During the design we have followed the following procedure



From the calculation we are able to calculate the following values

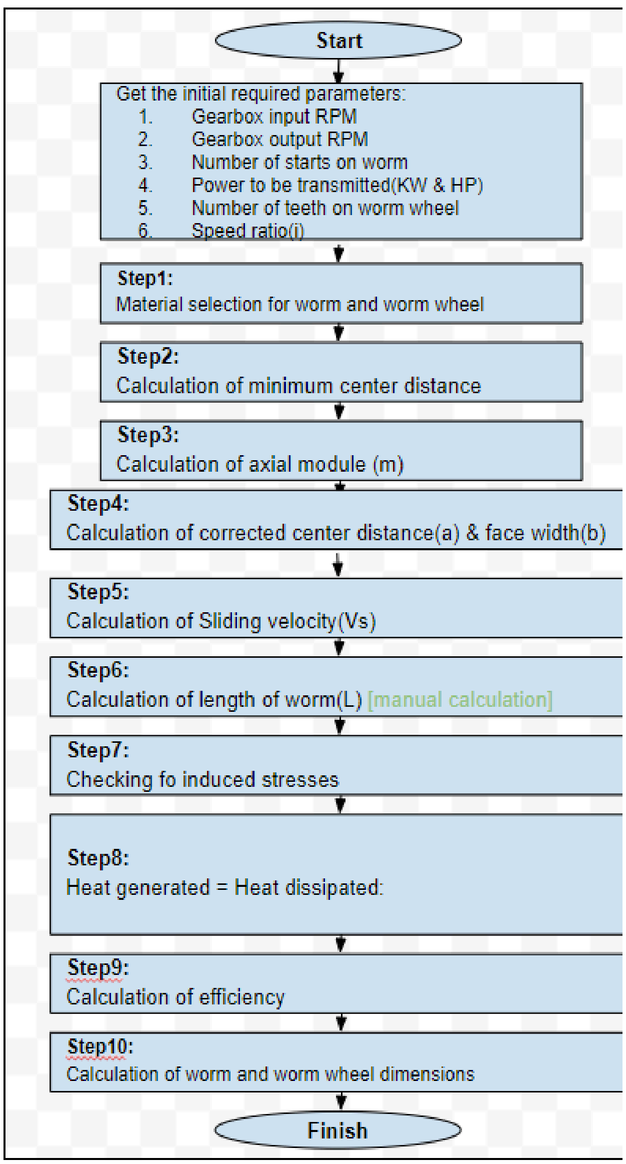
Sr.no	Parameter	value	Unit
4	Time required to lift to given height with given velocity	36.66666667	sec
1	Output energy required to lift without frictional losses	302148	joules
2	Actual motor energy required including frictional losses	335720	joules
3	Required motor power	9156	watt
4	Motor Power rating in HorsePower	12.27345845	Horse Power

4. Worm Gearbox

A worm gear (or worm drive) is a specific gear composition in which a screw (worm) meshes with a gear/wheel similar to a spur gear. The set-up allows the user to determine rotational speed and also allows for higher torque to be transmitted. An electric motor or engine applies rotational power via to the worm. The worm rotates against the wheel, and the screw face pushes on the teeth of the wheel. The wheel is pushed against the load. Applications - Lifting Devices, Cranes, Elevators, Belt conveyors etc. The main reason we are using worm gearbox in elevator is that it provides larger speed reduction ratio. Also, it provides the self-locking ability and high efficiency.

Fig 2: worm and worm wheel

Flowchart



From the above design procedure, we are able to calculate the following values of worm and worm wheel.

Worm gear dimensions:

Srno.	Parameter	Value	Unit
1	Worm addendum (ha1)	10	mm
2	Worm dedendum (hf1)	11.64513802	mm
3	Clearance(c)	1.96773982	mm
4	Outside diameter of worm(da1)	130	mm
5	Root diameter of worm (df1)	86.70972396	mm
6	Worm Pitch diameter(d1)	110	mm
7	Axial pitch(Px)	31.4	mm
8	Lead of worm(l)	62.8	mm
9	Length of worm(L)	186	mm
10	Lead angle(gamma)	10.30485015	degrees
11	Helix angle(psi)	79.69514985	degrees
12	Number of threads	5.923566879	-
	Rounded up value	6	-

Worm wheel dimensions:

Srno.	Parameter	Value	Unit
1	Worm wheel addendum(ha2) at throat	9.677398202	mm
2	Worm wheel dedendum (hf2) at throat	11.96773982	mm
4	Throat diameter of worm wheel(da2)	619.3547964	mm
5	Root diameter of worm wheel(df2)	576.0645204	mm
6	Pitch diameter of worm wheel(d2)	600	mm
7	module	10	mm

Solidworks modelling and drafting

1) Worm gear

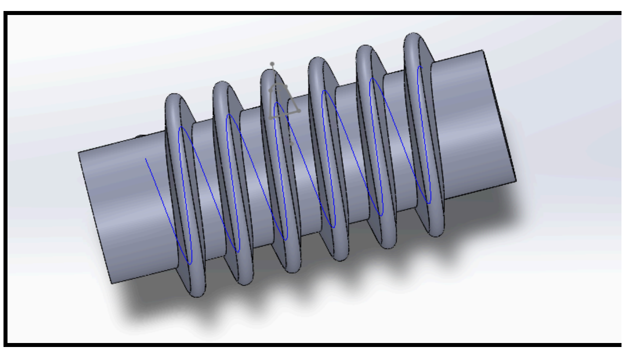


Fig 3: worm gear model in solidworks

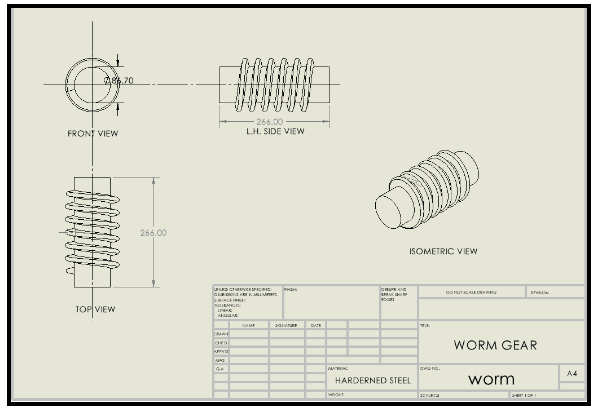


Fig 4: worm gear drafting in solidworks

2) Worm wheel

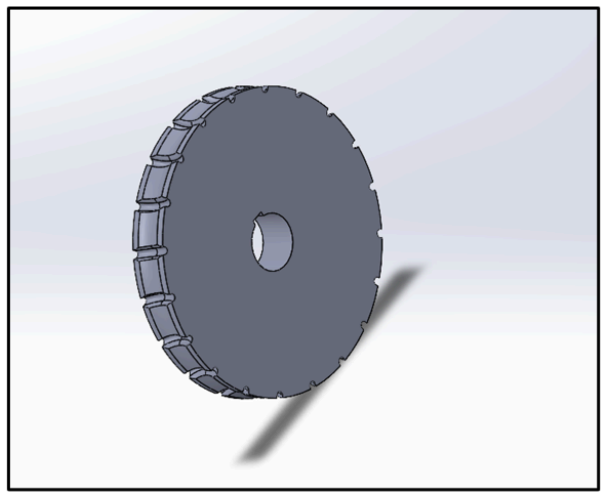


Fig 3: worm gear model in solidworks

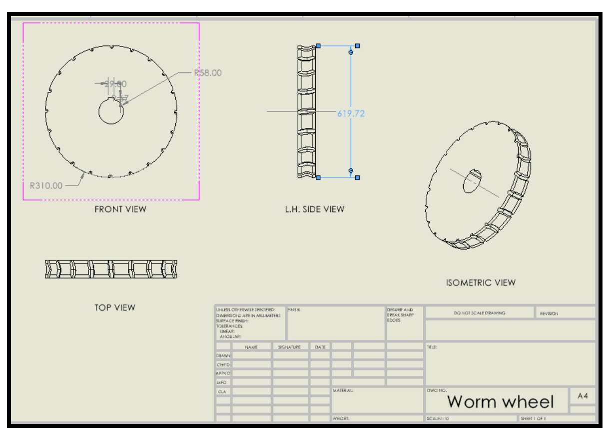


Fig 4: worm wheel drafting in solidworks

5. Shaft Design

Shaft is a common and important machine element. It is a rotating member, in general, has a circular cross-section and is used to transmit power. The shaft may be hollow or solid. The shaft is supported on bearings and it rotates a set of gears or pulleys for the purpose of power transmission. The shaft is generally acted upon by bending moment, torsion and axial force. Design of shaft primarily involves in determining stresses at critical point in the shaft that is arising due to aforementioned loading.

Material for Shafts:

i. Hot-rolled plain carbon steel

These materials are least expensive. Since it is hot rolled, scaling is always present on the surface and machining is required to make the surface smooth.

ii. Cold-drawn plain carbon/alloy composition

Since it is cold drawn it has got its inherent characteristics of smooth bright finish. Amount of machining therefore is minimal. Better yield strength is also obtained. This is widely used for general purpose transmission shaft.

iii. Alloy steels

Alloy steel as one can understand is a mixture of various elements with the parent steel to improve certain physical properties. To retain the total advantage of alloying materials one requires heat treatment of the machine components after it has been manufactured. Nickel, chromium and vanadium are some of the common alloying materials. However, alloy steel is expensive. These materials are used for relatively severe service conditions. When the situation demands great strength then alloy steels are used.

In our project we have selected the 50C4 material for the shaft. We have taken 50C4 Material for shaft: steel with 0.50 % carbon and 0.4 % manganese. The reason behind we use this material for shaft is that it Balances ductility and strength and has good wear resistance.

Fig 5: stepped shaft

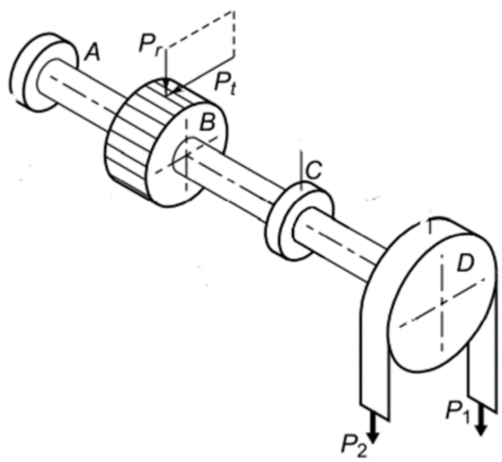
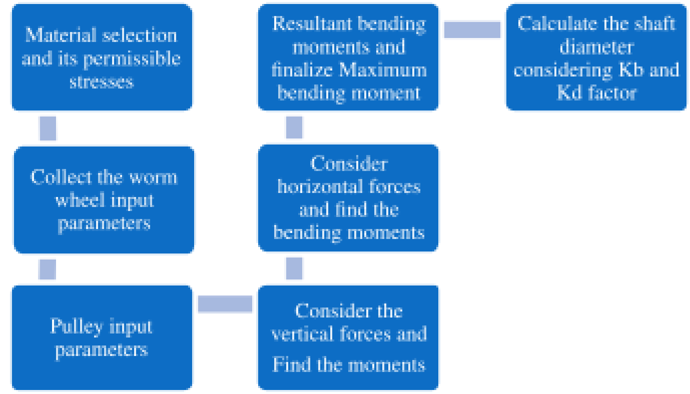


Fig 6: Gear and pulley arrangement on shaft

Here in fig 6 we can see that on the shaft two components are mounted i.e, worm gear and pulley at the end. Shaft is supported by two bearings on both the side of worm gear

Design flowchart:



MATERIAL SELECTION AND PERMISSIBLE STRESSES

I. We have taken 50C4 Material for shaft : steel with 0.50 % carbon and 0.4 % manganese.

II. Sut: 700 N/mm2 and Syt: 460 N/mm2.

III. Permissible shear strees:

a) 0.3 * Syt: 138 N/mm2

b) 0.18 * Sut: 126 N/mm2

c) Select lower from these two values as we have keyway.

d) Maximum shear stress: 0.75*126: 94.5 N/mm2

WORM WHEEL INPUT PARAMETERS

1. From the excel calculation we are able to calculate different parameters which are

taken into considerations for shaft calculation:

a) Torque transmitted: 3861603.03 N-mm

b) Tangential force on tooth: 12872.01 N

c) Radial load on tooth: 13698.10 N

PULLEY INPUT PARAMETERS

1. As pulley is mounted on the end of the shaft we have to take some parameters into consideration:

    a) Weight of the pulley: 294.3 N

    b) Tension in belts – T1: 61157.69 N, T2: 48155.66 N

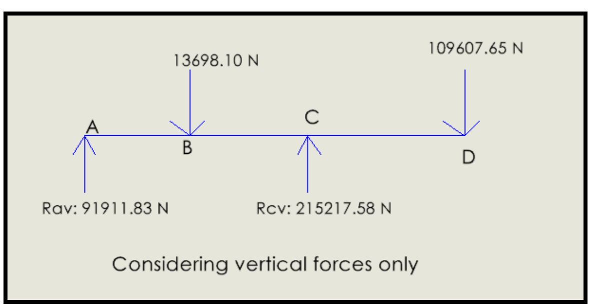
    c) Total force acting downwards from pulley: T1 + T2 + W: 109607.65 N

VERTICAL FORCES AND BENDING MOMENT

a) Ma & Md: 0

b) Mb: -18382.366 N.mm

c) Mc: -39480.354 N.mm



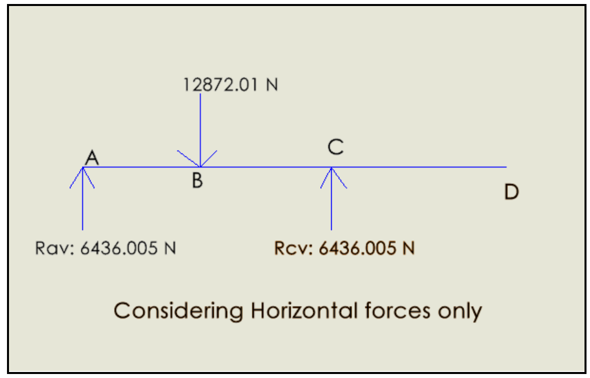
Considering vertical forces only

HORIZONTAL FORCES AND BENDING MOMEN

a) Ma & Md: 0

b) Mb: 18427378.17 N.mm

c) Mc: 39480.354 N.mm



Considering Horizontal forces only

RESULTANT BENDING MOMENT

1. From previous two slides we are able to calculate bending moments in horizontal and vertical direction hence now we need to find resultant bending moment.

2. Resultant bending moments:

    a. Mb: 18427378.17 N.mm

    b. Mc: 39480.354 N.mm

    c. Max Bending moment:

    d. Mb: 18427378.17 N.mm

CALCULATE SHAFT DIAMETER USING ASME CODE

1. In order to calculate shaft diameter using ASME code we have to consider following formula
2. From this formula we are able to calculate the diameter of shaft i.e. 116 mm

$$d^3 = \frac{16}{\pi \tau_{\max.}} \sqrt{(k_b M_b)^2 + (k_t M_t)^2}$$

where,

k_b = combined shock and fatigue factor applied to bending moment

k_t = combined shock and fatigue factor applied to torsional moment

The values of k_b and k_t for rotating shafts are given in Table 9.2.

Table 9.2 *Values of shock and fatigue factors k_b and k_t*

Application	k_b	k_t
(i) Load gradually applied	1.5	1.0
(ii) Load suddenly applied (minor shock)	1.5–2.0	1.0–1.5
(iii) Load suddenly applied (heavy shock)	2.0–3.0	1.5–3.0

Modelling and Drafting

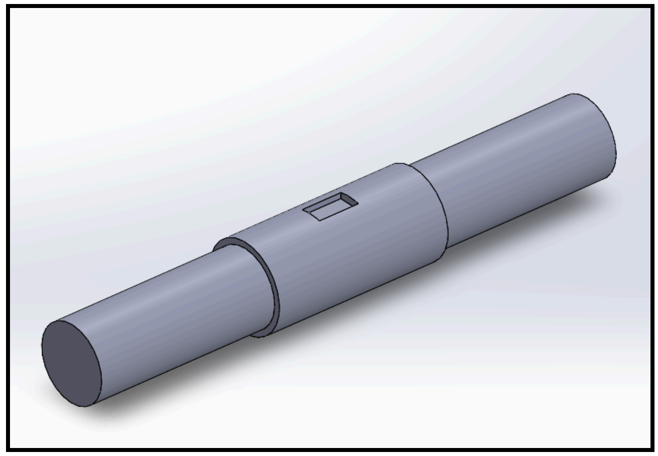


Fig 6: stepped shaft in solidworks

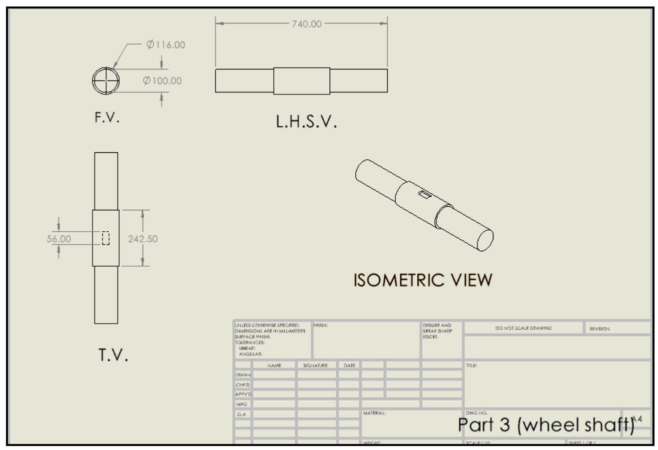


Fig 7 stepped shaft sheet

6. KEY

A key can be defined as a machine element which is used to connect the transmission shaft to rotating machine elements like pulleys, gears, sprockets or flywheels. There are two basic functions of the key. They are as follows:

a. The primary function of the key is to transmit the torque from the shaft to the hub of the mating element and vice versa.

b. The second function of the key is to prevent relative rotational motion between the shaft and the joined machine element like gear or pulley.

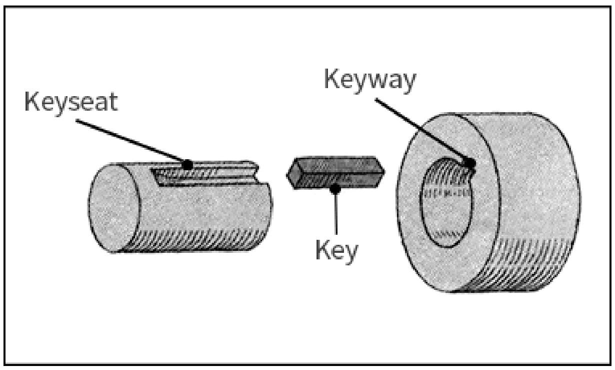
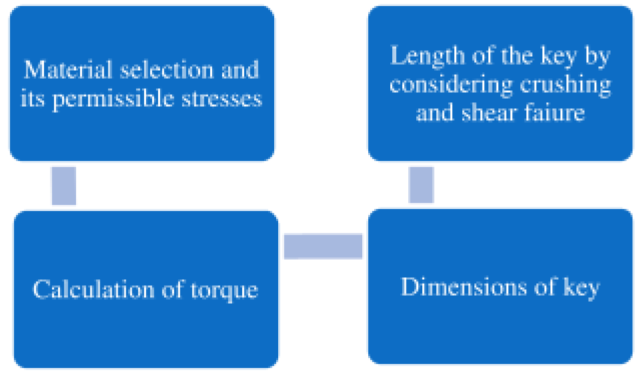


Fig 6: shaft and key arrangement

MATERIAL USED

In this application we have used 50C4 material for shaft. steel with 0.50 % carbon and 0.4 % manganese. The reason behind we uses this material for shaft is that it Balances ductility and strength and has good wear resistance.

Design flowchart:



MATERIAL SELECTION AND PERMISSIBLE STRESSES

We have taken 50C4 Material for shaft: steel with 0.50 % carbon and 0.4 % manganese.

Step I *Permissible compressive and shear stresses*

$$S_{yc} = S_{yt} = 460 \text{ N/mm}^2$$

$$\sigma_c = \frac{S_{yc}}{(fs)} = \frac{460}{3} = 153.33 \text{ N/mm}^2$$

According to maximum shear stress theory of failure,

$$S_{sy} = 0.5\, S_{yt} = 0.5\,(460) = 230 \text{ N/mm}^2$$

$$\tau = \frac{S_{sy}}{(fs)} = \frac{230}{3} = 76.67 \text{ N/mm}^2$$

CALCULATION OF TORQUE

a) With the help of power formula, we can find out the torque:

b) T: 4774.64 Nm

$$M_t = \frac{60 \times 10^6 (kW)}{2\pi n}$$

DIMENSIONS OF KEY

a) According to empirical relation we have found out the dimensions of key:
b) b-width of the key- d/4= 116/4= 29 mm
c) H- height of key- d/6= 116/6= 19.33 mm

LENGTH OF KEY

1. By considering the shear failure and crushing failure we have calculated two lengths:
   a. By considering shear failure length of key is: 37.02 mm

$$l = \frac{2M_t}{\tau db}:$$

   b. By considering crushing failure length of key is: 55.54 mm

$$l = \frac{4\,M_t}{\sigma_c\,dh}$$

MODELING AND DRAFTING

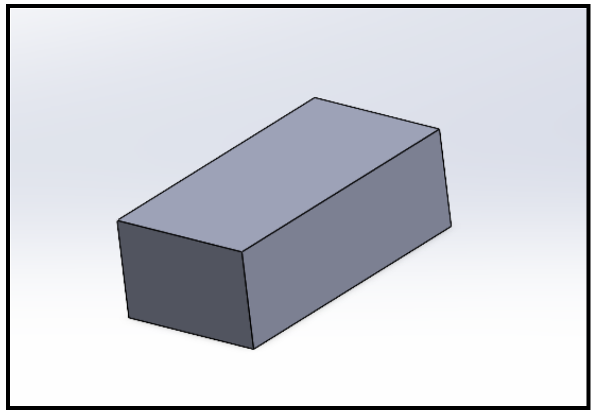


Fig 8: Key in solidworks

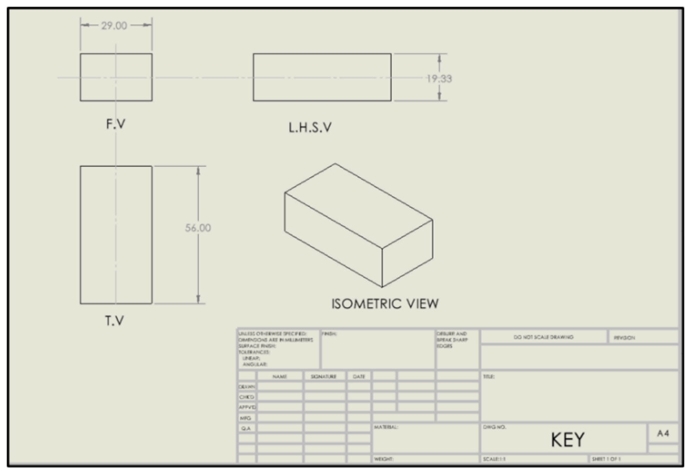


Fig 9: Key sheet

7. Belt Drive

In this project we have used the belt drive in order to transmit the power from motor to worm shaft. We have used belt drive for safety purpose. V-belts are made of polyester fabric and cords, with rubber reinforcement. The cords transmit the force from the driver to the driven pulley, thereby transmitting the power. The number of cords is increased based on the force requirements. The rubber layer transmits the force in the cord to the side layers.

The cross-section of the V-belt is shown in Fig below.

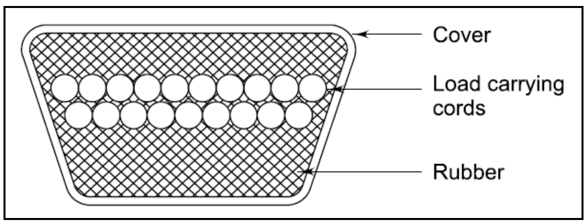


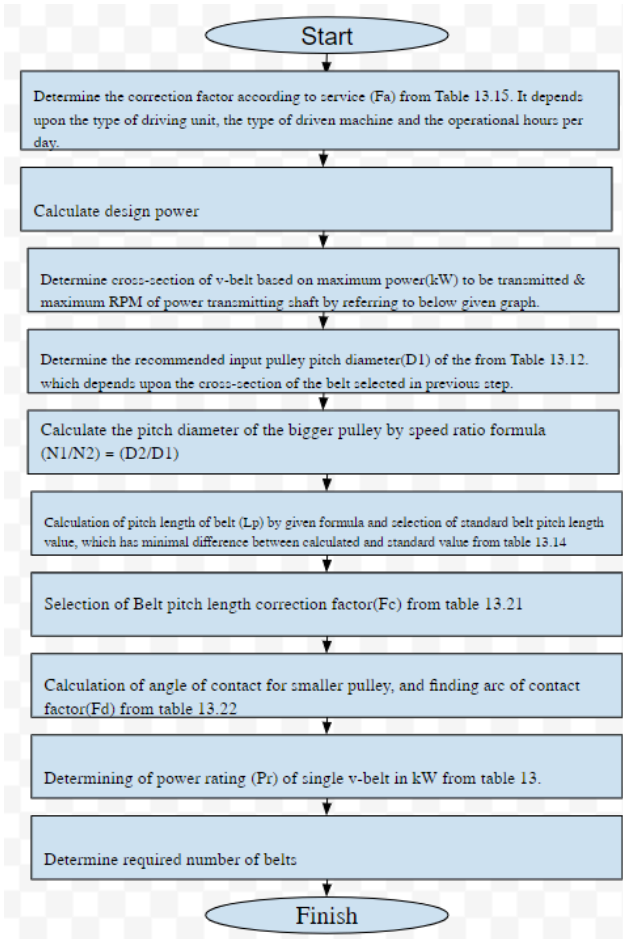
Fig 9: V Belt

It consists of the following three parts:

1. the central load carrying layers of polyester cords or polyester fabric, which are located on horizontal lines near the centre of gravity of the belt cross-section:
2. the surrounding layer of rubber to transmit force from cords to side walls, and
3. outer polychloroprene impregnated elastic cover.

The polyester cords or fabric transmit force from the driving pulley to the driven pulley, which in turn transmit power. Since they are located near the neutral axis of the cross-section of the belt, the stresses due to bending of the belt around the pulley are almost negligible. The layer of rubber located above the load carrying cords is subjected to tension and called tension layer. Similarly, the layer of rubber below the central cords is subjected to compression and called a compression layer.

Design Flowchart



According to above design procedure:	Value	Unit	
1. Diameter of Input pulley (D1)	200	mm	
2. Diameter of output pulley (D2)	480	mm	
3. Belt Specification	B	4060	Lp
4. Approximate required number of belts (N)	3		
5. Center distance (C)	1489.34	mm	

8. Rope drive

In this project we have used rope drive in order to lift the elevator car from ground floor to top floor. It is generally mounted on pulley. Here we have used wire rope. Wire rope, is a type of cable which consists of several strands of metal wire laid (or 'twisted') into a helix. The term cable is often used interchangeably with wire rope. However, in general, wire rope refers to diameters larger than 3/8 inch. Sizes smaller than this are designated as cable or cords.

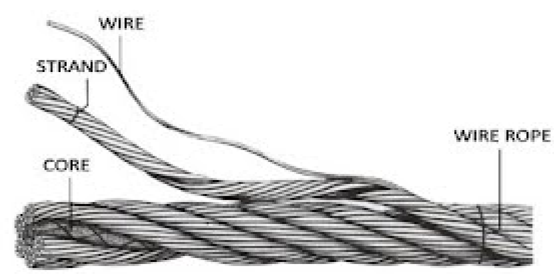


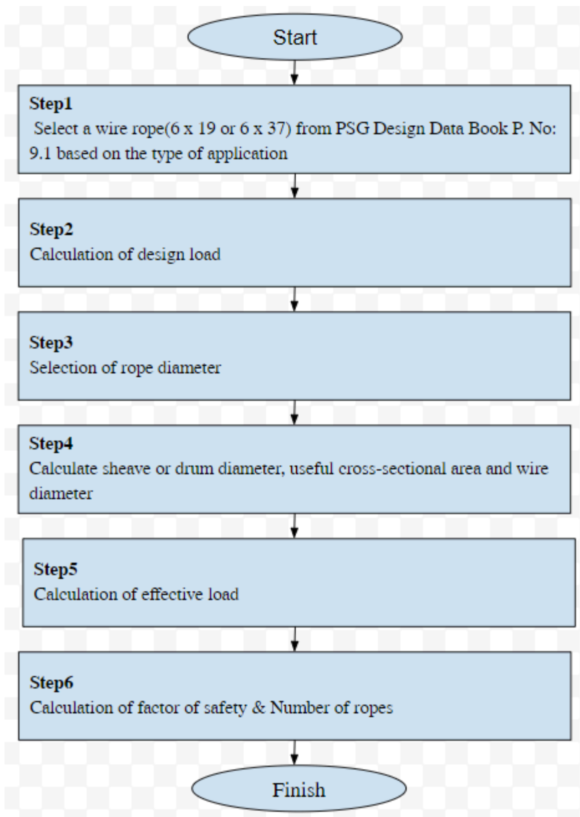
Fig 9: wire rope

Strand

Groups of strands wrapped in a uniform helix around a core. Strand is two or more wires wound concentrically in a helix. They are usually wound around a centre wire.

Lay

The lay of the strand, wire rope or cable, is the direction in which the helix of the wires orbit the core. An easy way to determine the lay is to hold the specimen vertically in front of you and observe whether the strands or wires travel up and to the right or up and to the left.



Materials of Wire Ropes

1. Wrought Iron
2. Cast Steel
3. Copper
4. Bronze
5. Stainless steel

According to the design procedure given above

Name	value	unit
Number of strands in rope	6	-
Number of wires in each strand	19	-
Weight of rope	1.84	kgf/m
For 22m length	40.48	kgf
No of Ropes	2	
Wire Diameter	2	mm
Sheave Diameter	594	mm
Total length	22	m

9. Counter Weight

Counterweights are often used in traction lifts (elevators), cranes and funfair rides. In these applications, the expected load multiplied by the distance that load will be spaced from the central support (called the "tipping point") must be equal to the counterweight's mass times its distance from the tipping point in order to prevent over-balancing either side. This distance times mass is called the load moment.

A counterbalance is a weight or force that balances or offsets another as when two objects of equal weight, power, or influence are acting in opposition to each other. The objects are then said to be in counterbalance.

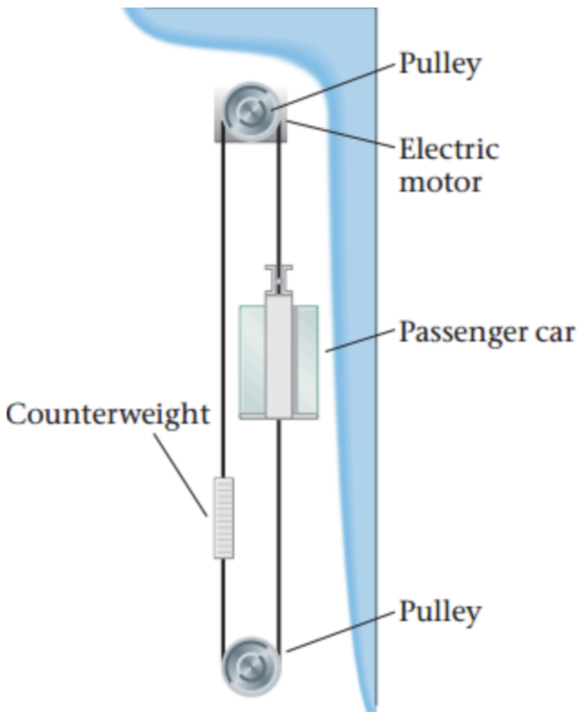


Fig 9: Counterweight arrangement

Why concrete weights over steel?

Density: Concrete's density can be improved by adding dense aggregates such as limonite, hematite, or magnetite, or metal bits and scraps into the concrete mix. This enables concrete block to achieve the target weight in less space and volume.

Cost: Cast iron is indeed stronger and harder and so the initially the cost of steel counterweights is more than concrete, whereas we can have same weight in a concrete form in much cheaper way.

Usually, metallic counterweights need screws for fastening or mounting additional equipment. Whereas concrete blocks don't need additions.

A counterweight is a weight that, by applying an opposite force, provides balance and stability of a mechanical system. The purpose of a counterweight is to make lifting the load faster and more efficient, which saves energy and is less taxing on the lifting machine.

Design of counterweight:

The elevator including passengers has mass M= 1400 kg and the counterweight has mass m 1400 kg: The motion of the elevator is controlled by setting the force F delivered by the motor: The acceleration due to gravity is g 9.8O m/s^2

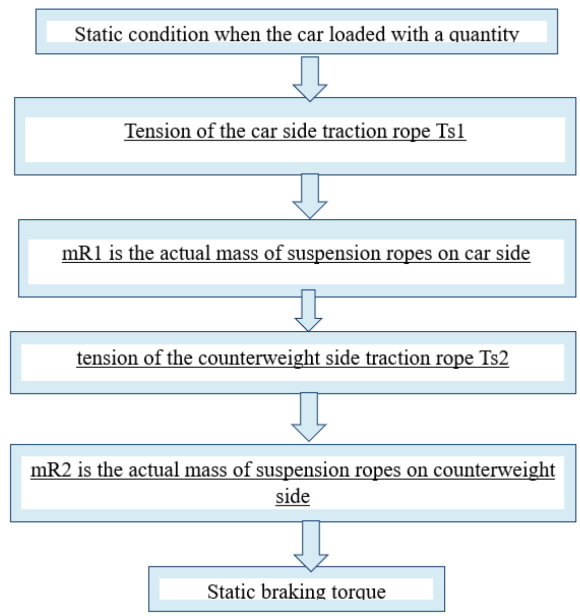
Counterweight = Elevators maximum capacity + cab weight

= (600+800)

= 1400 kg

10. Drum Brake

Elevators are used to transport passenger one floor to another and load in vertical directions. Hence, they are expected to offer a comfortable and safe service to their passengers in the buildings. Brakes are used as safety systems in elevators. There are more than one safety systems in elevators which one of them is double –shoe brake system. The brakes used in elevators have two basic tasks. Firstly, they are responsible for holding the elevator stable when it is not in operation, and secondly for stopping the cab in the desired floor as commanded by the user. According to the standards, the electromechanical brakes that intervene should be used in elevators' drive mechanism. For this aim, when the electromechanical brakes are not using any reasons, double-shoe brake system is capable of stooping the car. In elevators, the brakes are active when the system is not in operation, which is not the case in other systems. The brake opens and starts its movement once the drive engine actuates. In case of a breakdown or power disruption, the brake can be activated manually by operating the lever on the braking system and automatically deactivated when this lever is released. The literature has few studies regarding the double- shoe braking systems used in elevators. These systems are often considered as same with the double-shoe braking systems used in vehicles.



According to above design procedure we have calculated the following parameters

Calculations:			
Sr No	**Parameter**	**Value**	**Unit**
1	Actual mass of suspension ropes on car side	36.9	kg
2	Tension of car side traction rope	4284.07	N
3	Actual mass of suspension ropes on counter weight	4.1	kg

4	Tension of C.W side traction rope	5430.18	N
5	Breaking torque	785	Nm
6	Tension of C.W side traction rope	6900.18	N

Calculations:			
Sr No	**Parameter**	**Value**	**Unit**
1	Angle of contact of each shoe(2theta)	1.75	rad
2	Spring force	12,812.30	Nm
3	Torque	668.25 / 198470.25	Nm

11. Conclusion

In this project we have design the elevator system for the capacity of 600 kg to transfer people on from bottom floor to 5th floor at the speed of 0.6 m/s. For this purpose, we have designed worm gearbox, motor drive, belt drive, rope drive, counterweight, shafts, drum brake etc. In this design parameters were considered with the application purpose of the mechanism.

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